Challenged Networking and Flying Ad-hoc Networks

Fundamentals of Information Systems
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Outline

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- Challenge Networks
  - Infrastructure Reliance
  - Basic Definition
  - Examples
- Flying Ad-Hoc Networks
  - Routing Issues
  - Position-based Routing Protocols
  - Routing in 3D networks
  - IoV Simulation
- FANETs as DTNs
  - Smart Aided routing for FANETs
  - Simulation assessment

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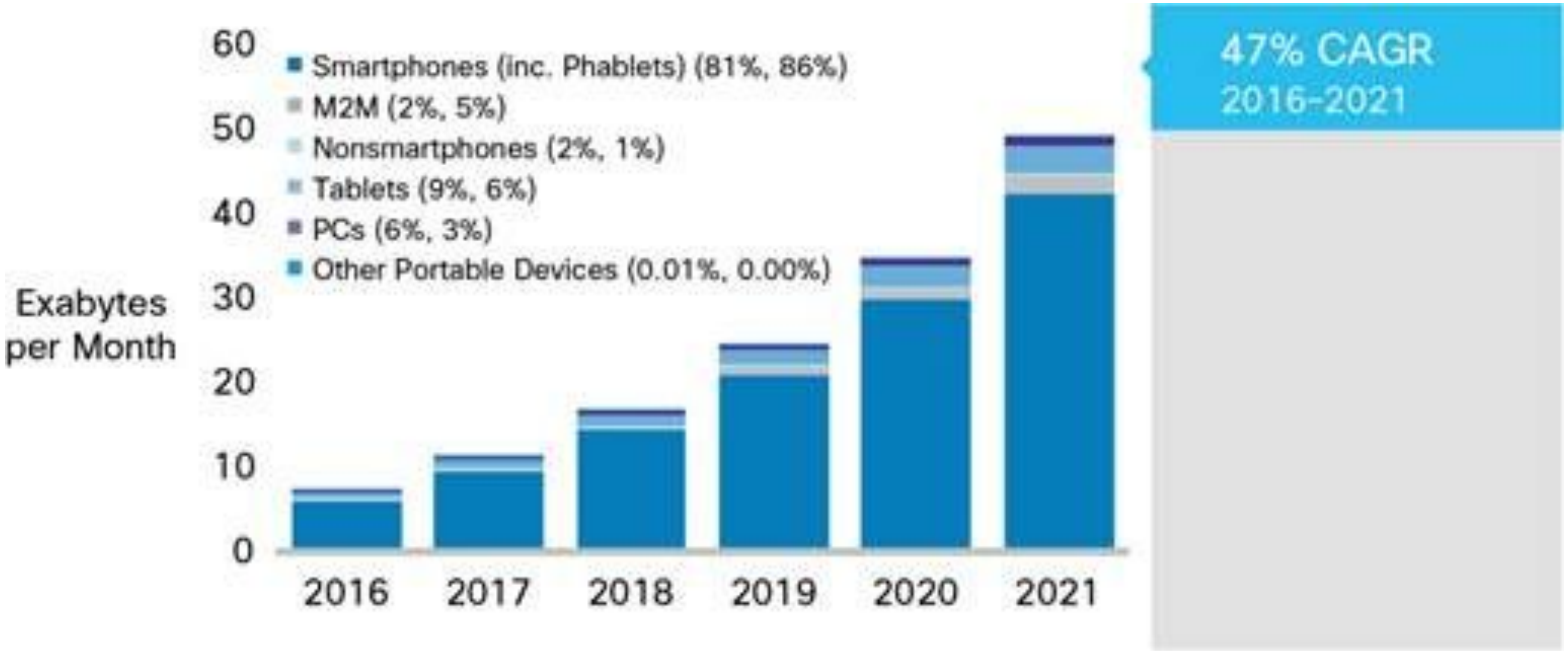
The mobile revolution

- User-generated content model (e.g., Youtube, Facebook)
- Disconnected, distributed data sources
- Access/distribution through infrastructure mediation



Infrastructure Reliance - Other Options?

- However, current infrastructure networks
  - Suffer from an exponential increase of data traffic
  - Lack of a service connectivity
  - A times, not feasible or cost-effective
- Idea: interaction without *strict* infrastructure reliance
  - Content produced/consumed locally
  - Data temporal/spatial validity compared to global/always on
  - Exploit **ad hoc** connectivity to exchange data

➡ *Opportunistic communication*

- Scope: *military, transportation, environmental monitoring, crisis and disaster management*

Challenged Networks

"Challenged" according to dictionaries:

Having disabilities or impairments - Deficient or lacking

Challenged networks

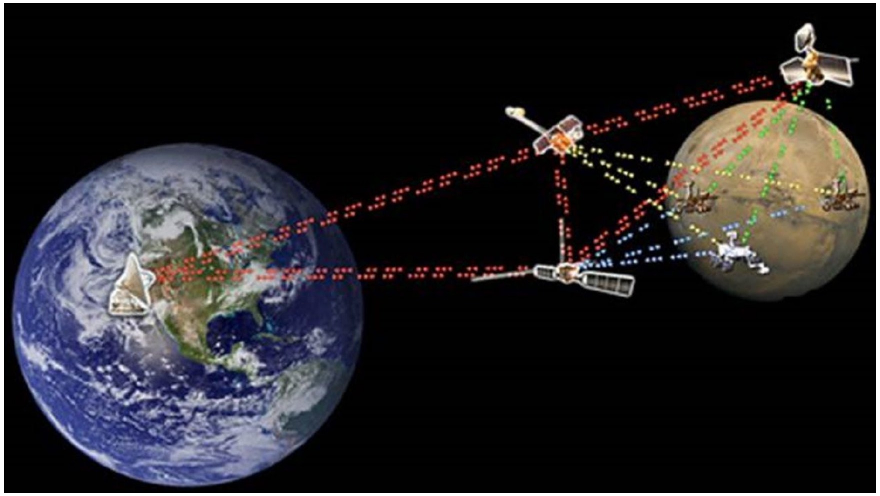
Networks facing challenges because of "disabilities / impairments / deficiencies" (compared to "normal/conventional/usual" networks)

- Examples of disabilities / impairments / deficiencies
  - High error rates
  - Asymmetrical bidirectional data rates
  - Intermittent end to end path

dealing of the problem

Outer space networks

- No continuous end-to-end path
  - Planet orbit and rotation
- High delays and prone to errors
  - Long distances



Wireless Sensor Networks

- Collecting ambient information
- Small scale devices
  - Stationary or mobile

Challenged Network: Examples

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- Vehicular Ad-hoc Networks
  - Based on Mobile Ad-hoc Networks
  - Nodes move within the constraints of road
  - Rapid topology Changes
    - Short link life
  - Fragmentation
    - Chunks of the net are unable to reach nodes in nearby regions
  - Limited redundancy
    - Critical providing additional bandwidth
- Flying Ad-hoc networks

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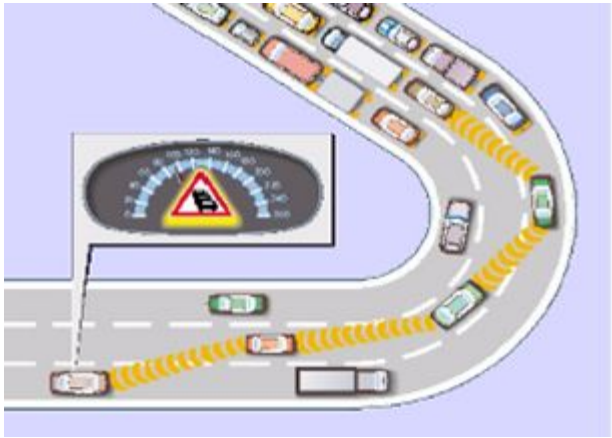
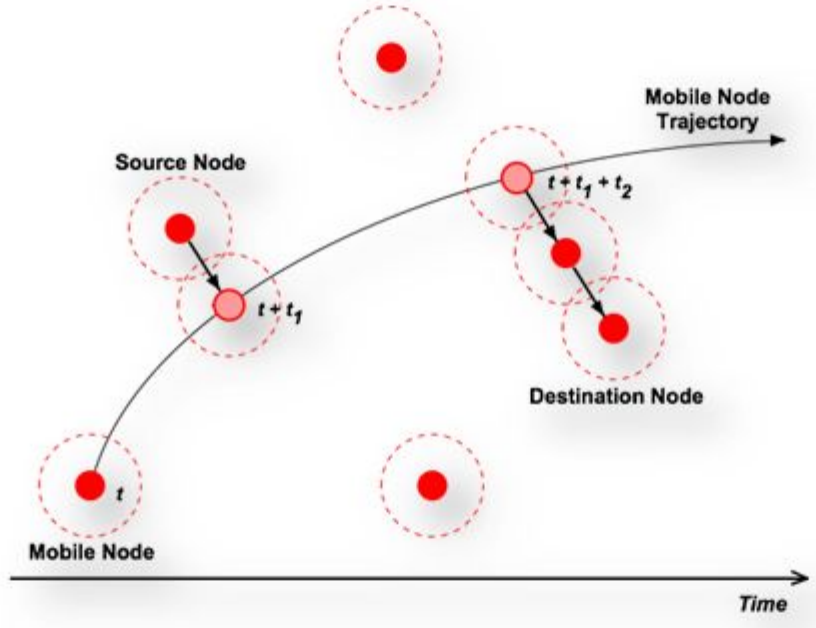


Opportunistic Forwarding

- Enables seamless communication by hiding discontinuity of end-to-end channel
- Caching at Road Side Units (RSUs)
- The challenge is:
  - Maximize delivery
  - Minimize latency



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Introduction

Drone - Flying Device

- Unmanned Aerial Vehicle (UAV)
- Unmanned Aircraft System (UAS)
- Remotely Piloted Aircraft (RPA)

Flying controllable/independent device without a human pilot aboard.

- Several application scenarios
  - Originated for military applications
  - Expanded in commercial, scientific, civil, ...
- Characteristics of UAVs
  - Typically use Wi-Fi technology (802.11) to communicate
  - Equipped with GPS, camera, sensors
  - Can be part of a **network**

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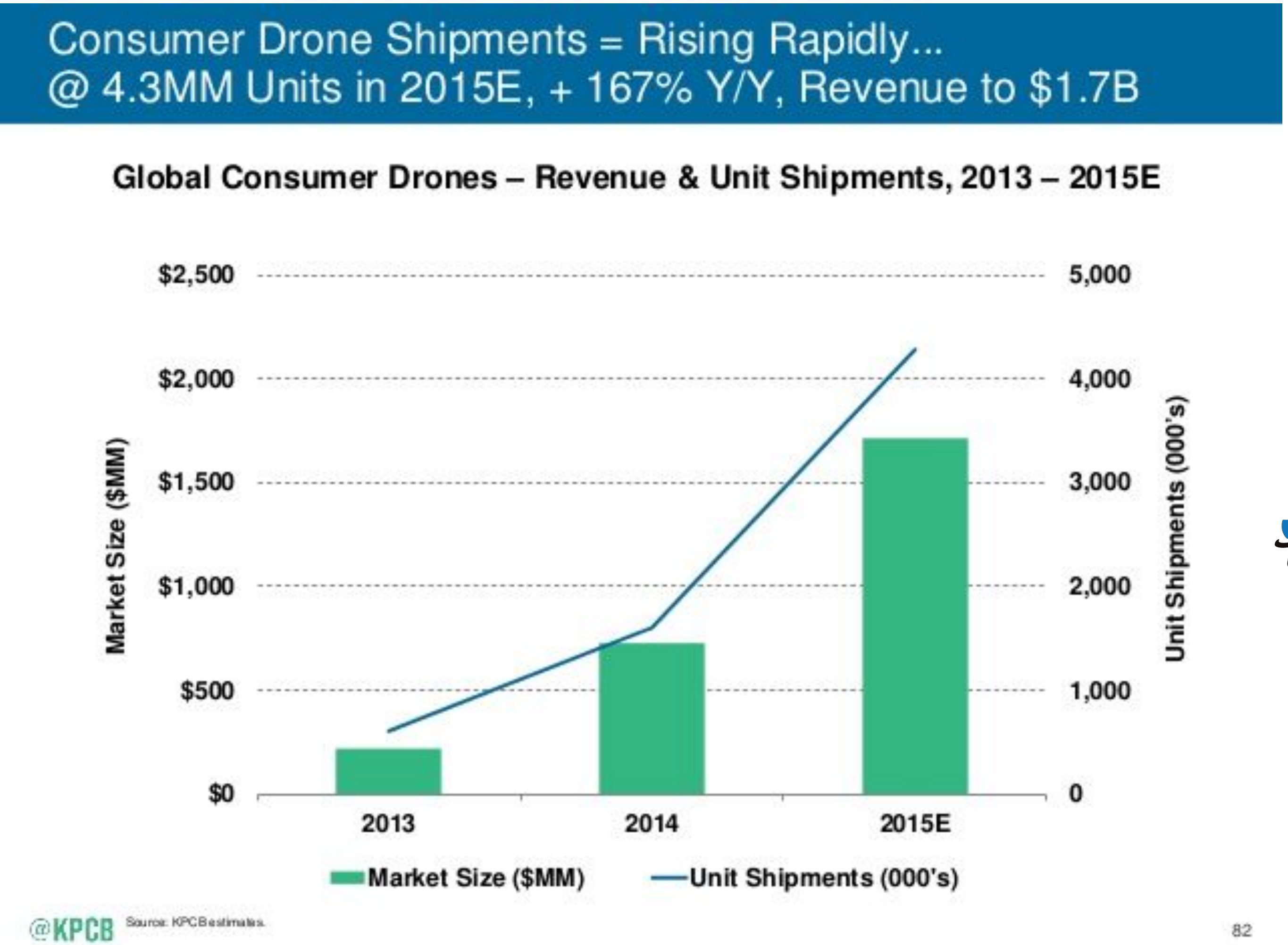
In recent years, drones business employs a tremendous growth, with estimates of over 1,5 billion sold by 2015.



Parrot

UAV TECHNOLOGY

Application of drones

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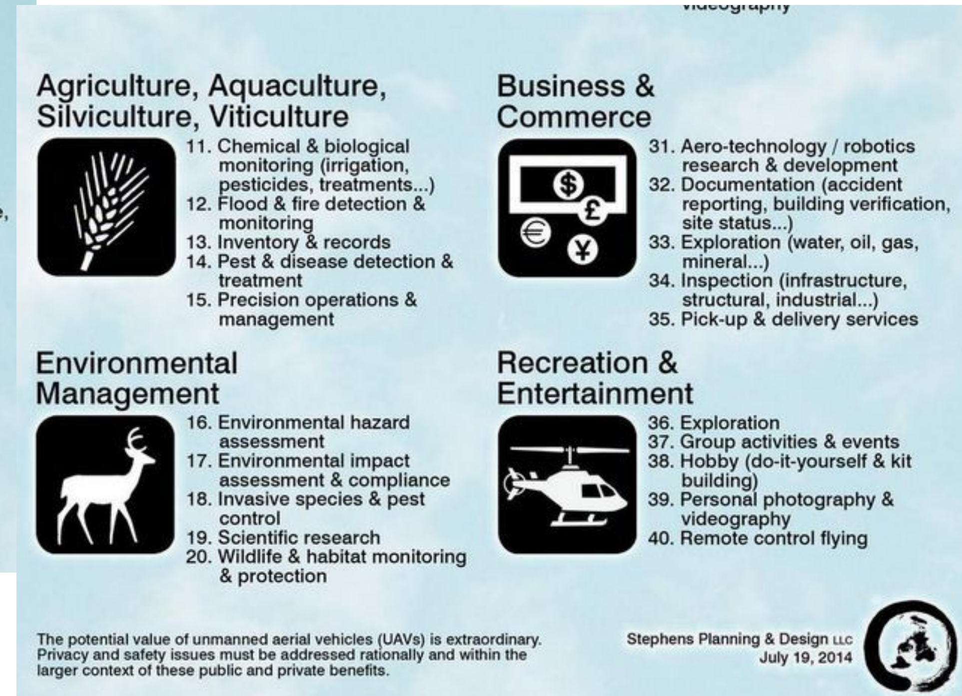
- Military
- Civil
- Business
- Scientific Research
- Hobby



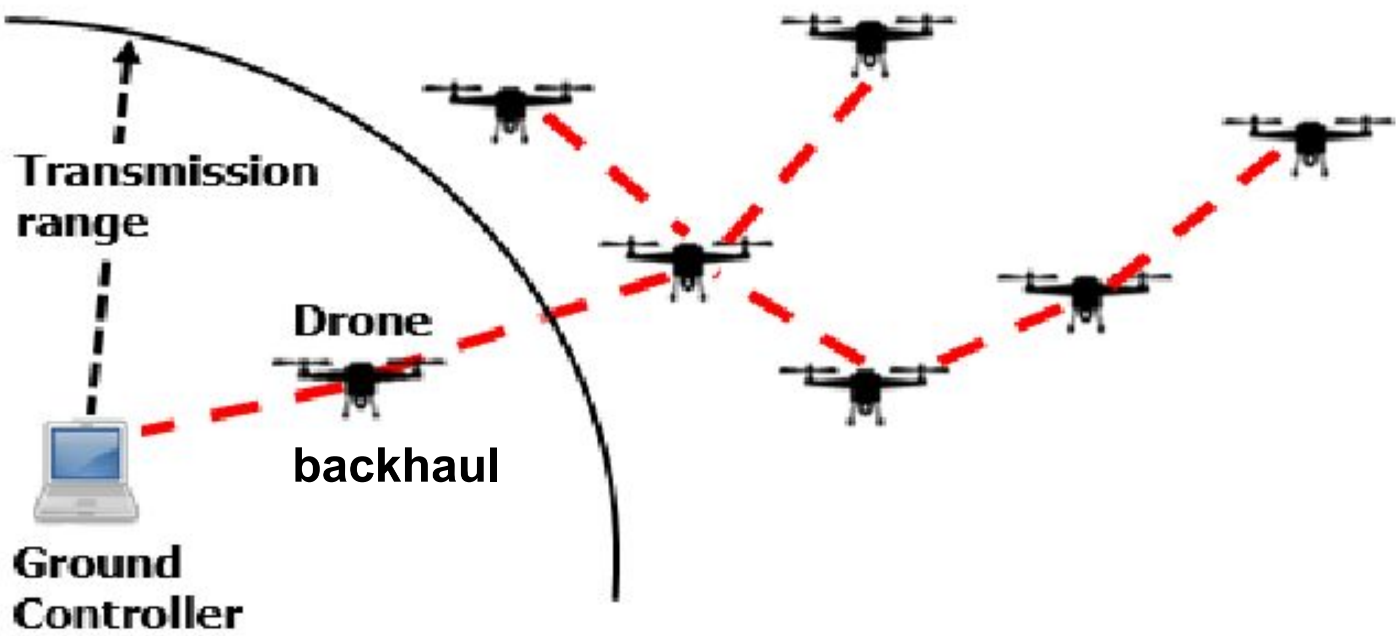
Flying Ad-Hoc Networks (FANETs)

- **Swarms of UAVs** are becoming a new solution for many applications
  - Search and rescue, patrolling, sensing, communication, disaster relief ...
- UAVs can communicate with each other in order to perform **cooperative tasks**
  - A network of UAVs is called ***FANET*** (Flying Ad-hoc NETwork)
    - Other terminologies: DANET / UAANET

Flying Ad-Hoc Networks (FANETs)

Two parts:

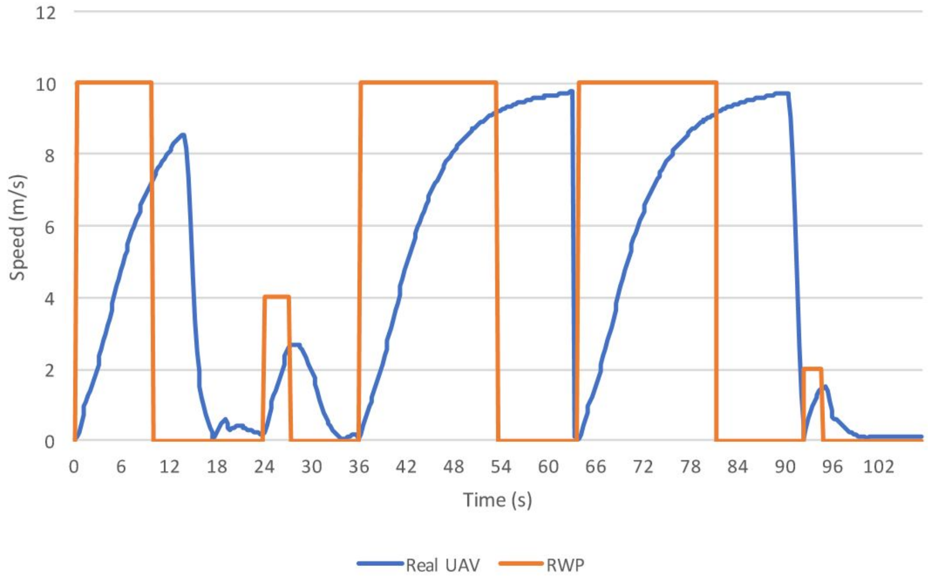
- Ad-hoc network
- Access point (satellite, ground base, laptop, ...)



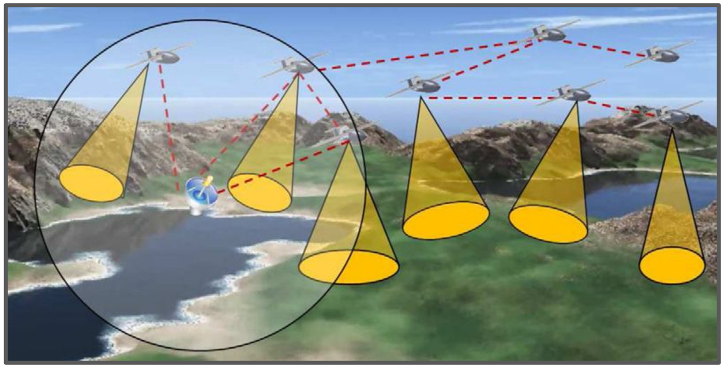
Differences between MANET and FANET

FANETs are a special case of mobile ad hoc networks (MANETs)

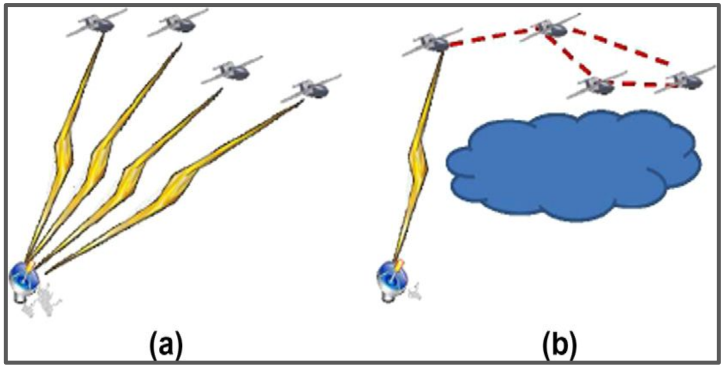
- Mobility model
  - Different speed
  - Different topology
  - Different movement
- Topology changes
  - More frequently link failures
  - Link quality changes
- Distances
- Equipments



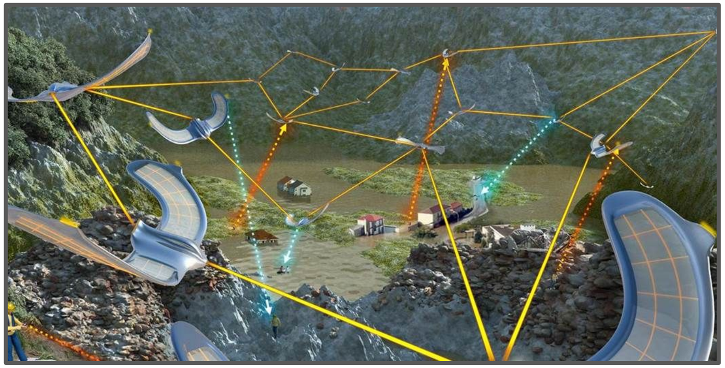
Motivation of FANETs



1. Extend the work coverage and range

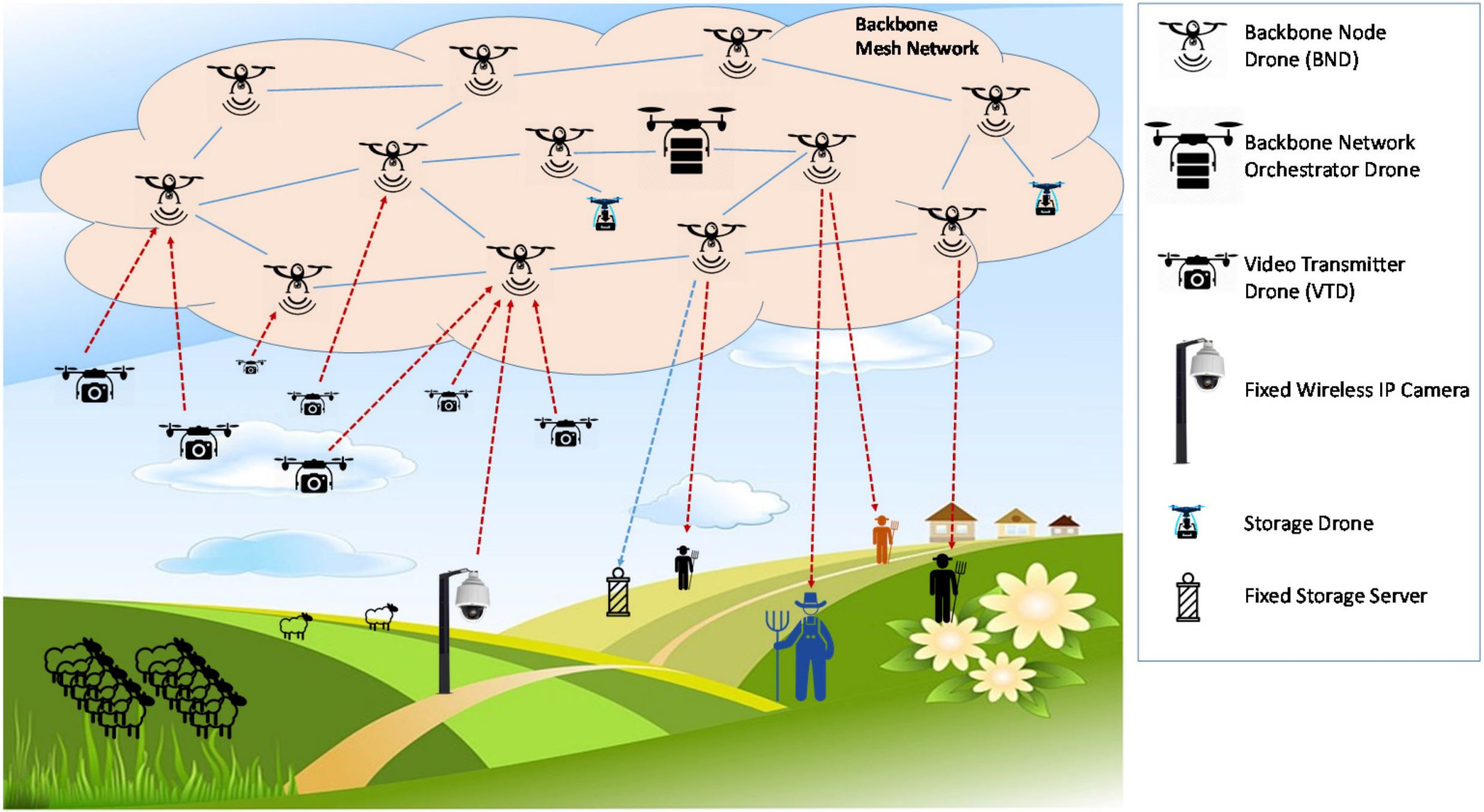


2. Reliable UAV system and communication



3. Cooperation, sustainability and distributed working

A FANET in a IoT scenario



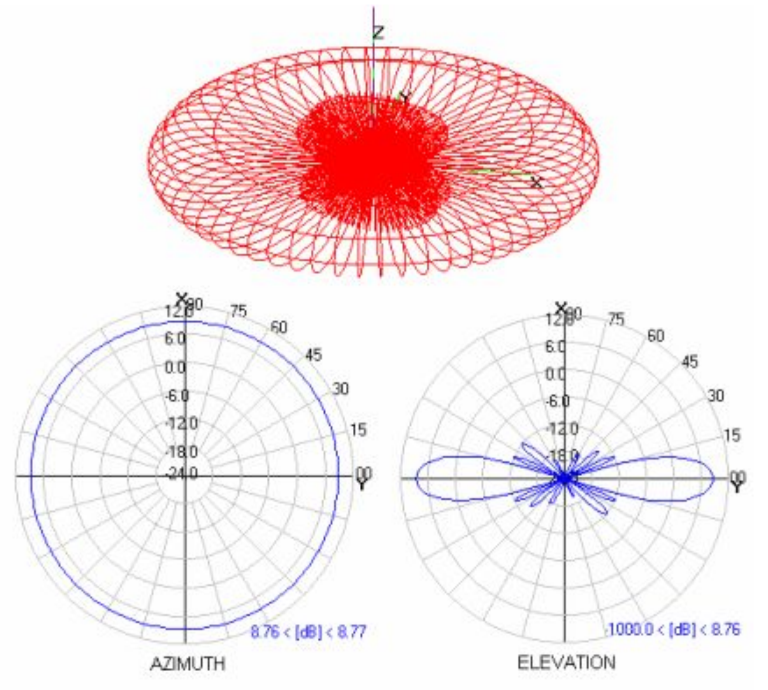
Communication in FANETs

Communication protocols in FANETs have still open research challenges

- Physical layer
  - Radio propagation
  - Antenna structure
- MAC layer
  - Link quality degradation
  - Adaptive MAC Protocol Scheme for UAVs (AMUAV)
- **Network layer**
  - Packet forwarding decision is more difficult
  - Maintaining of routing tables
- Transport layer
  - Reliability
  - Disconnections

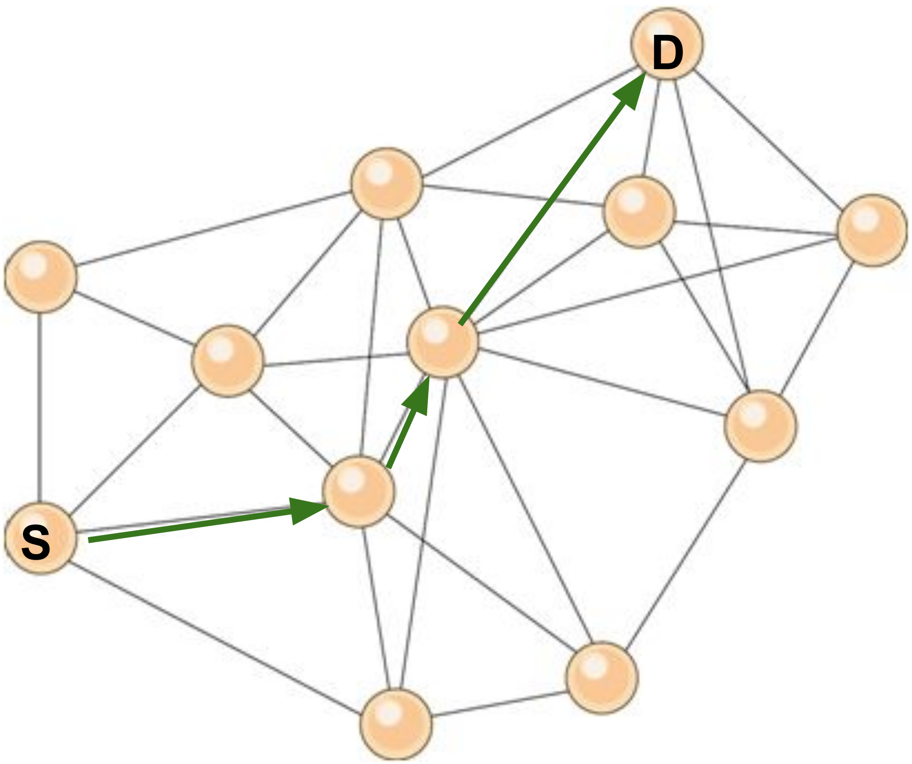
Routing in FANETs

- Routing in a MANET needs a multi-hop forwarding of packets
  - Difficult due to the continuous change of topology
- Routing in a FANET is even more difficult ...
  - More speed
  - Different density
  - 3D topology
  - Different radio propagation
  - Power consumption
  - ....



Challenge of routing in FANETs

- Typically connectionless
  - Every packet treated separately
- Main routing challenges
  - Link failures
  - Limited bandwidth
  - Limited energy
- Two main approaches
  - Topology-based
  - **Position-based**



→ Focus on **node's location information**
to support route decision

Topology-based

- Use information about links
- Routing table
- Proactive, reactive and hybrid approaches
- Reactive approach is more suitable for MANETs
  - Need route only when required
  - There are not continuous table updates
  - AODV, DSR, etc ..

node 2's route table

seq	dest	next	hop
1	1	1	1
1	3	3	1
1	4	3	2

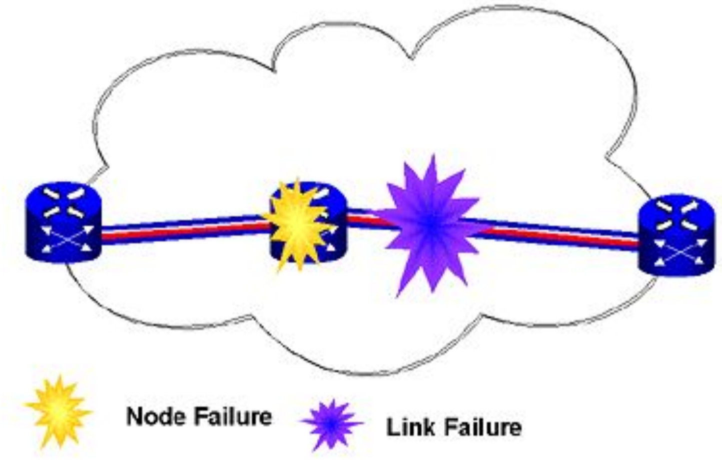
node 1's route table

seq	dest	next	hop
1	2	2	1
1	4	2	3

Topology-based

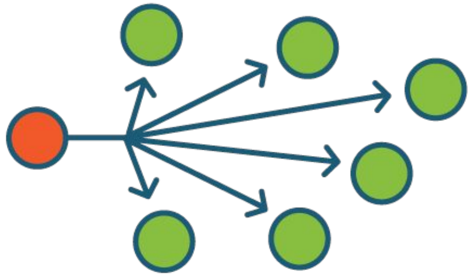
- There are some limitations also using these protocols in FANETs, especially with
  - Limited bandwidth
  - Limited energy
  - Limited memory

Link failures / node failures



Huge amount of control traffic

- Some topology approaches need to **flood** the request packets
- Much information have to be **frequently updated**

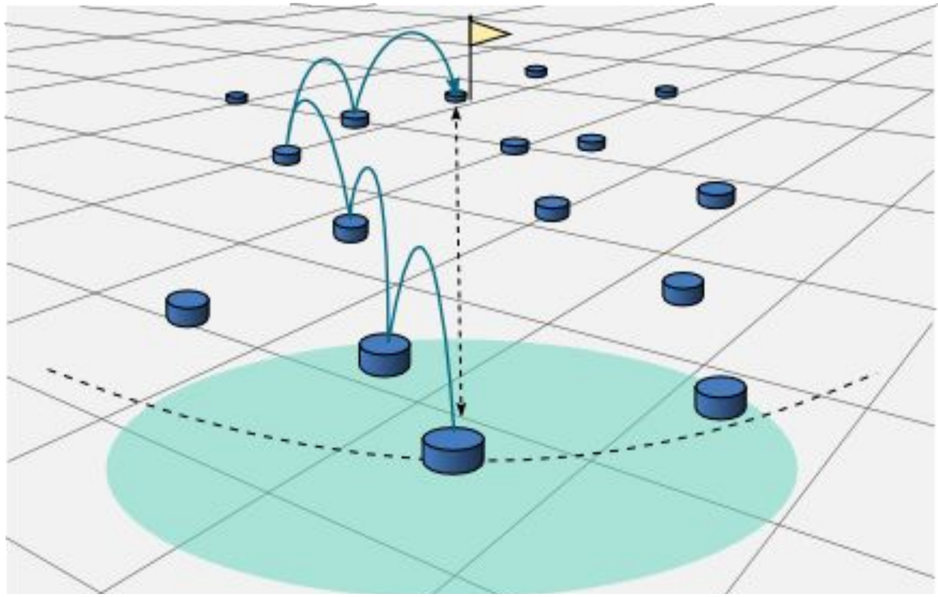


Topology-based solution are not as scalable

Position-based

- Use geographic position information for packet forwarding decision
    - Location service (GPS)
- No need for a routing table
    - Only neighbors' information
    - Limited control overhead

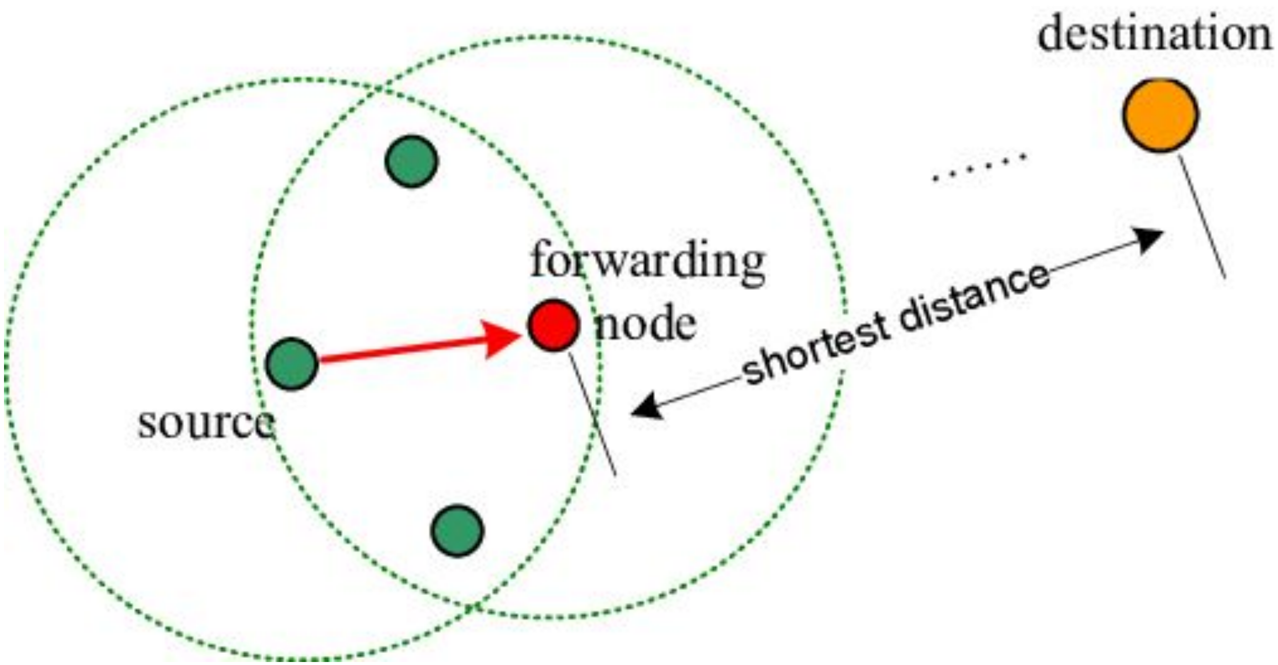
MORE SCALABLE



- Current node chooses the best next-hop node toward the destination node
- But.. the **Hello messages**? --> constant control overhead
    - Adaptive Hello timer

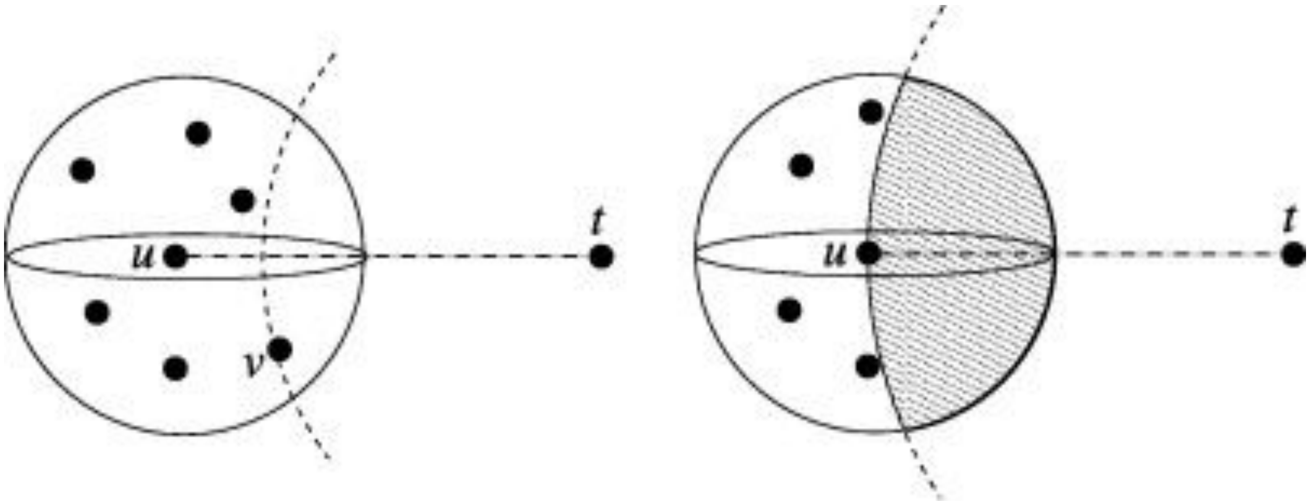
A trivial approach: GREEDY

- A node forwards the packet to one of its neighbors that make **progress** toward the destination (<u>Greedy</u>)
  - Distance
  - Projected distance
  - Angle



A trivial approach: GREEDY

- Greedy approaches suffer of the problem of **local minimum**
  - The packet gets stuck in a node
  - Sometimes the packet does not arrive at destination

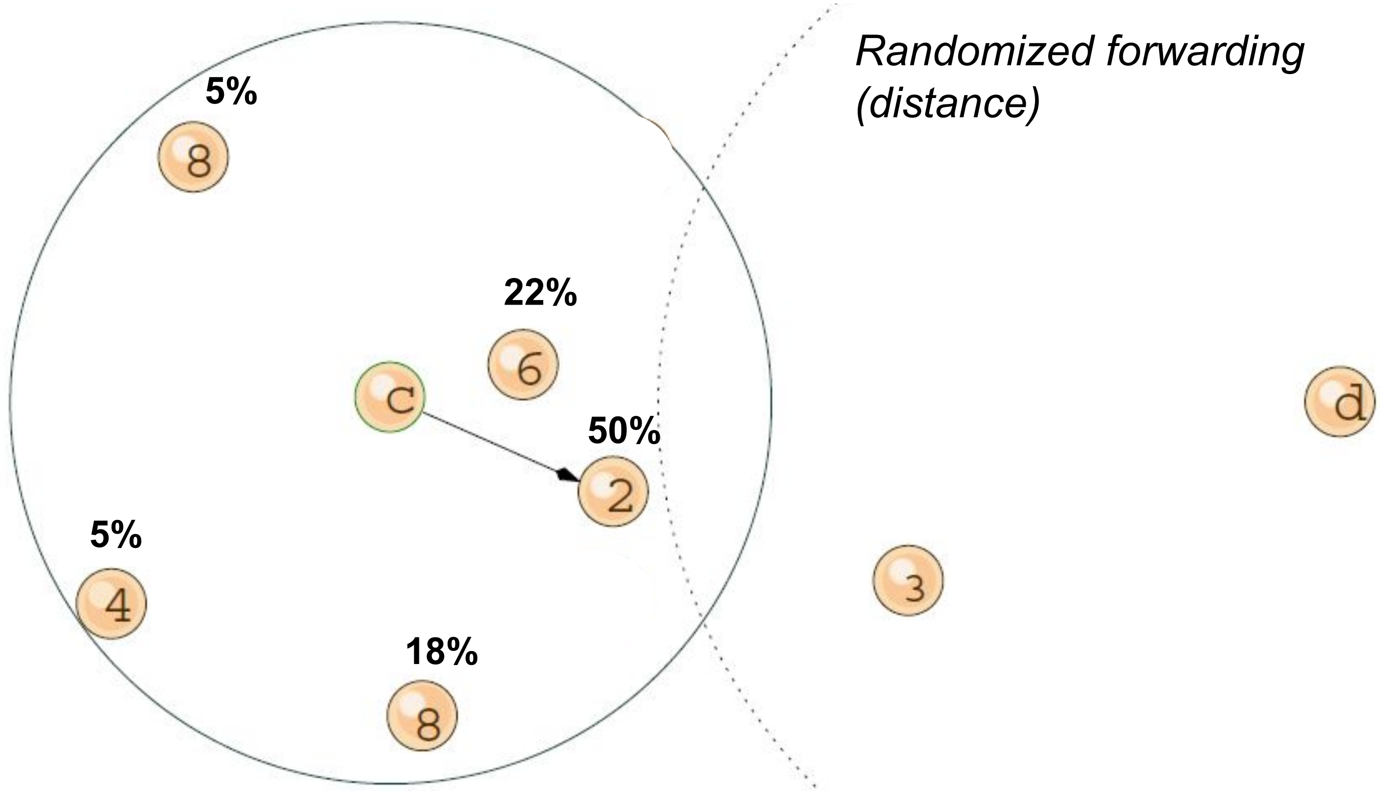


(a) forwarding neighbor (b) local minimum

Greedy approach need to be binded with a <u>recovery strategy</u>

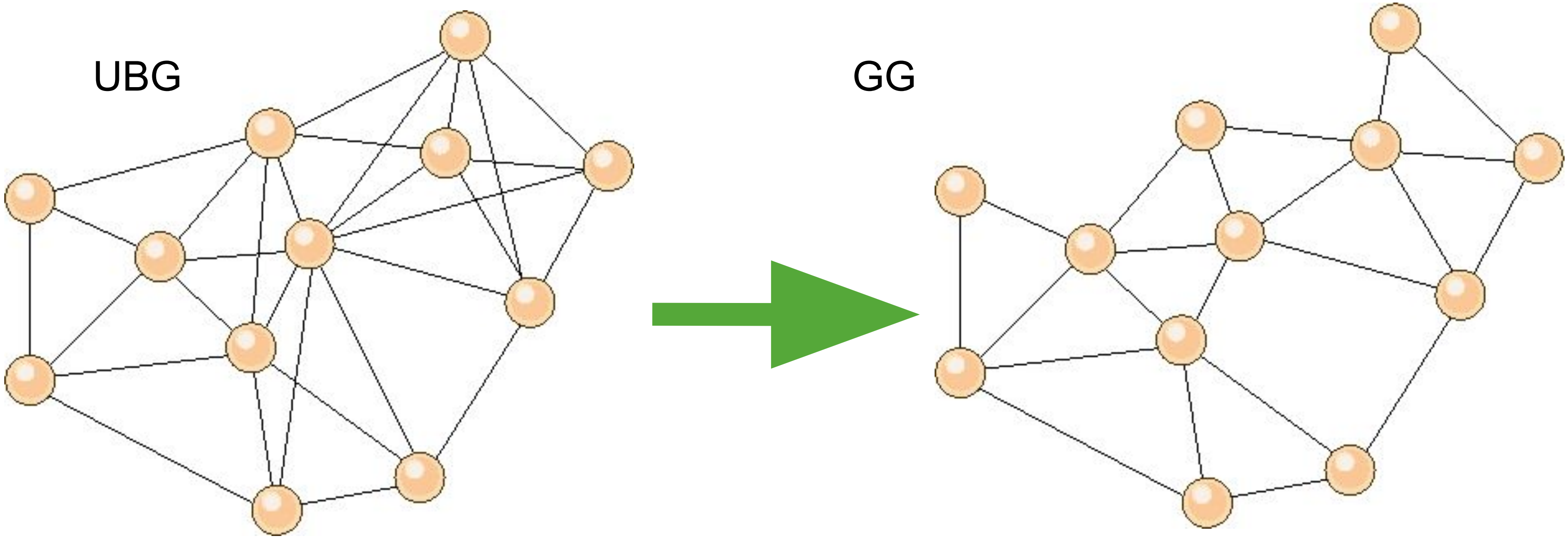
A randomized approach

- The packet is forwarded to a certain node with a **probability** that increases with the **progress** that would be made towards destination



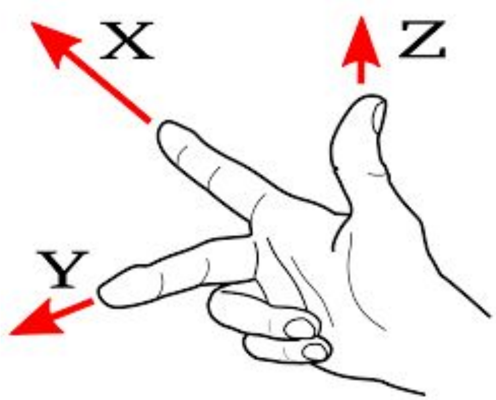
A recovery strategy

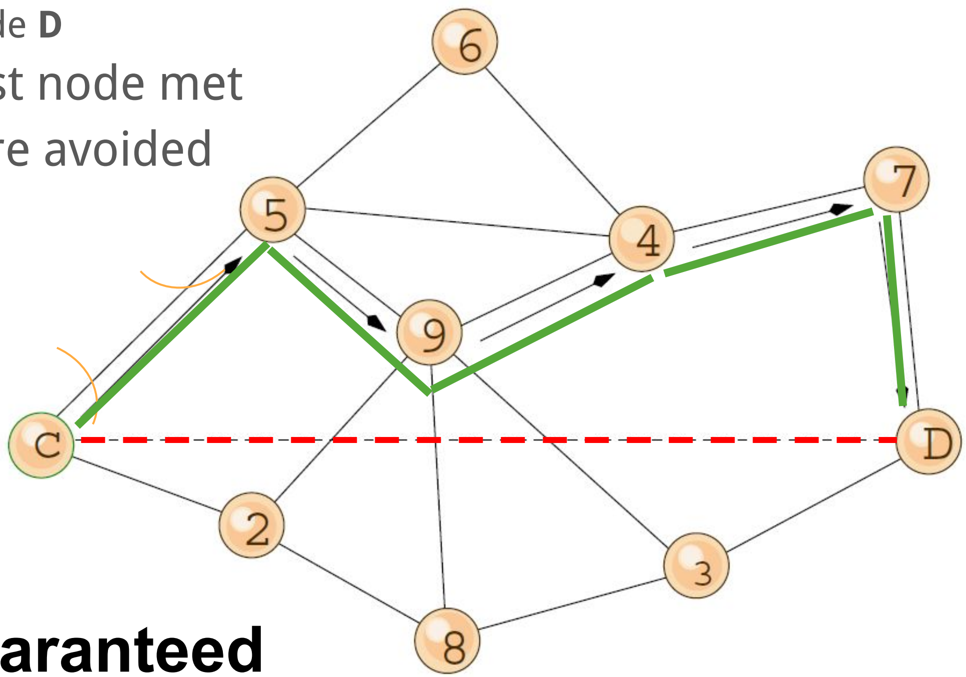
- **Face** routing algorithm
  - The packet walks adjacent faces to reach the destination
  - Graph planarization → planar sub-graph
  - Remove cross-links



Face algorithm

- Right-hand rule (or left-hand rule)
- Looking for the first node at the right (left)
    - Starting from the line represented by the link from where the packet arrived
        - Only the **first iteration** starts from line starting from the local minimum **c** (or source node) and the destination node **D**
    - The packet is sent to the first node met
    - Links crossing the line **cD** are avoided



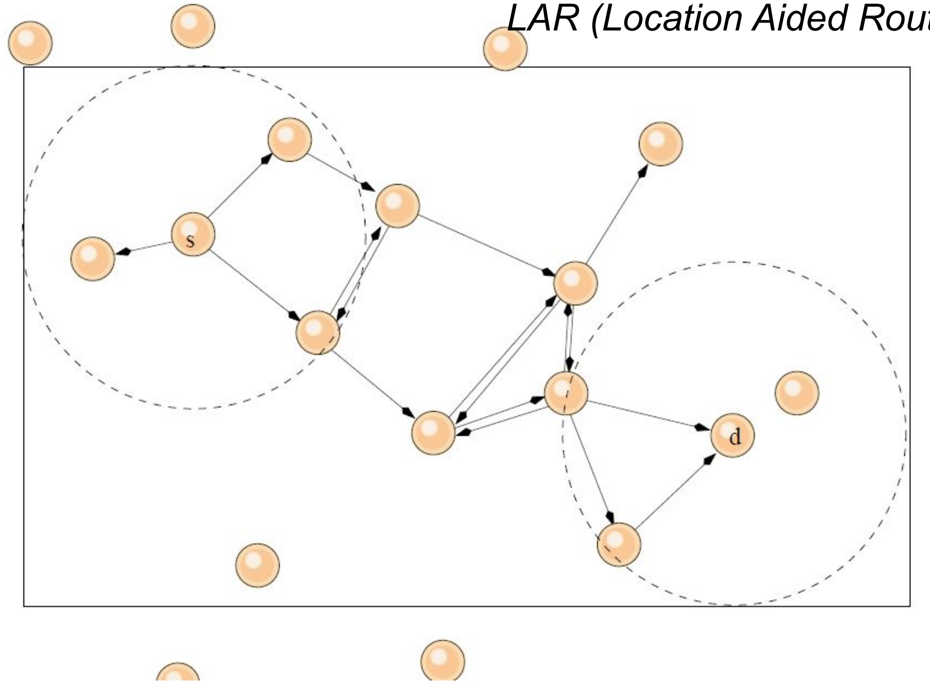


Delivery of packet is guaranteed

Multi-path forwarding

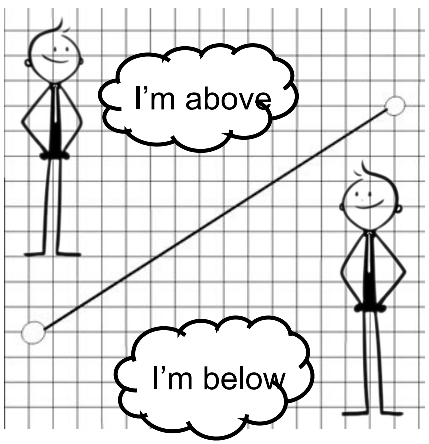
- A node send the same packet to multiple neighbors
- **Location Aided Routing** algorithm: uses a rectangle that includes transmission ranges of source and destination
- Limited flooding

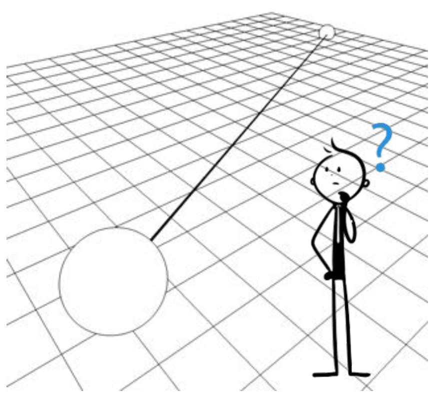
LAR (Location Aided Routing)

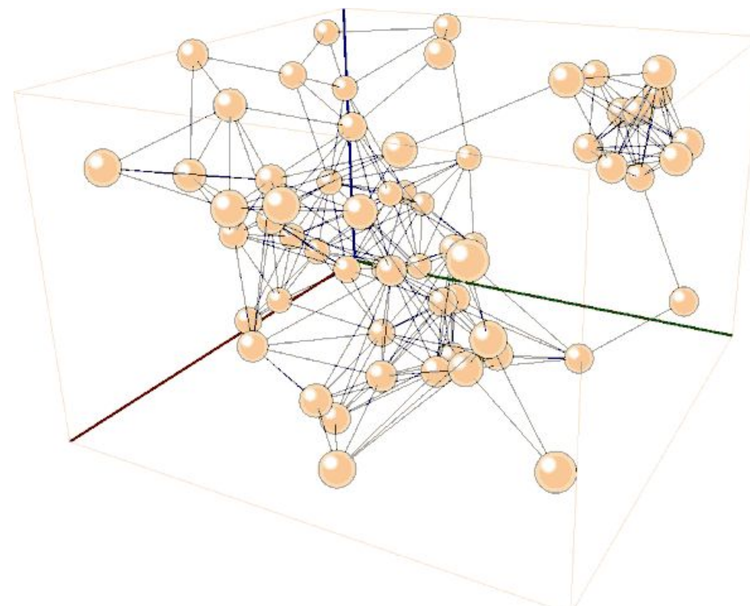


What if 3D networks?

- Many researches on position-based routing focused on 2D networks models
  - E.g., Vehicular Ad-hoc Networks (VANETs)
- FANETs are intrinsically 3D
- Difficult to extend 2D concepts to 3D space
  - NO planarization
  - NO above and below a line

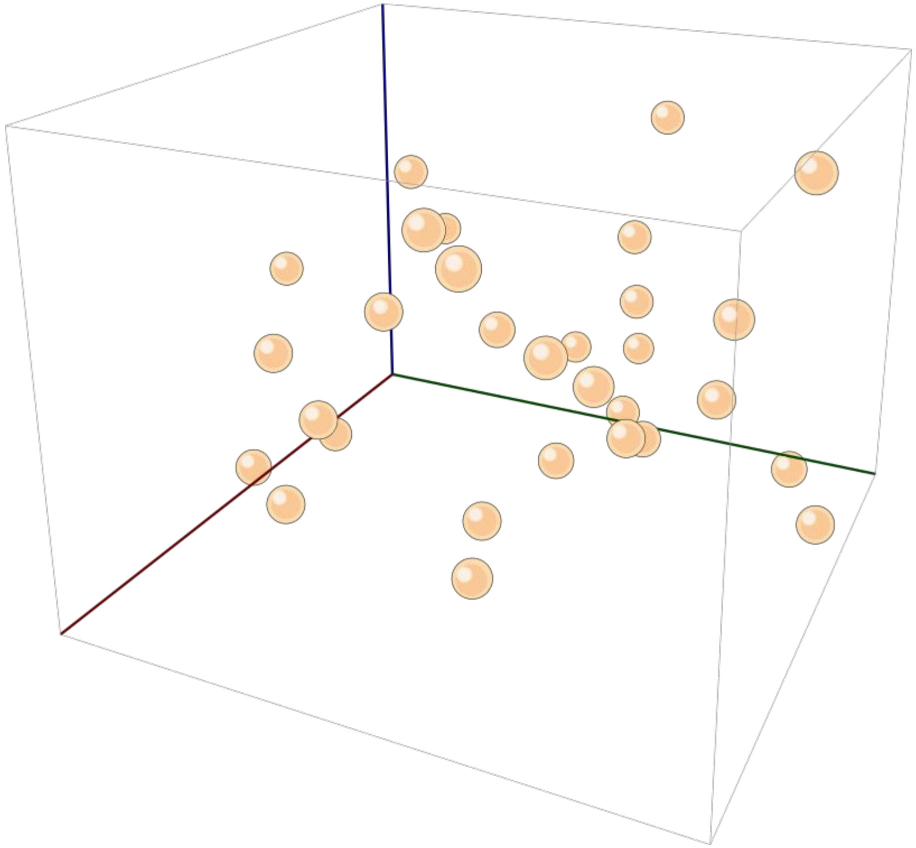






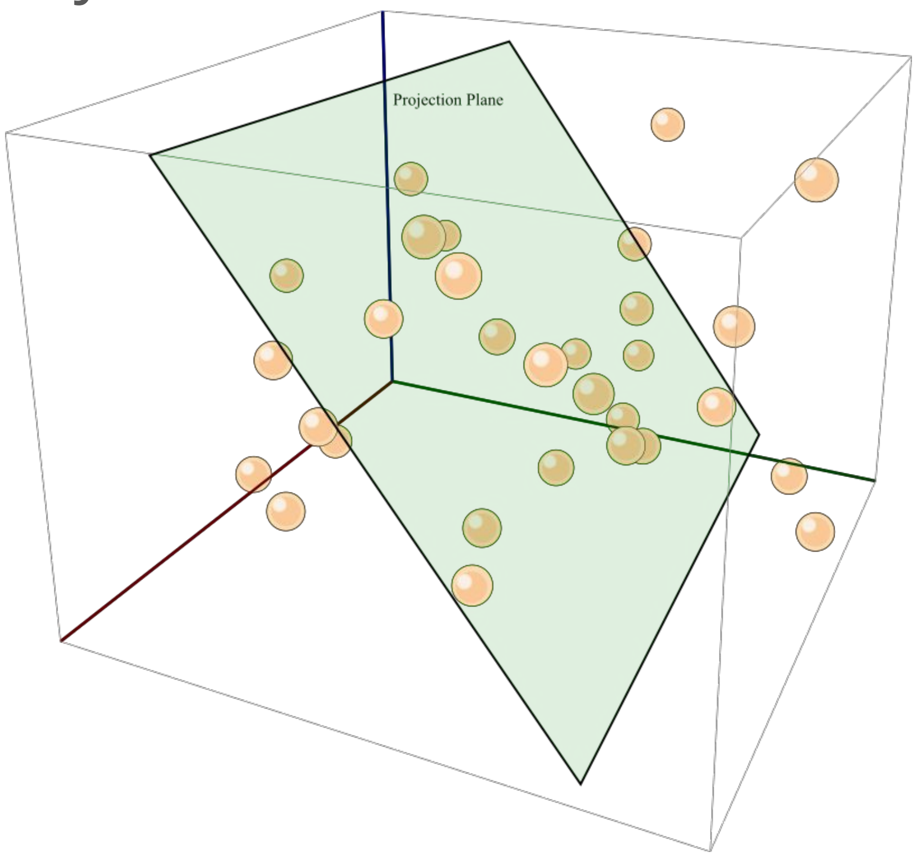
3D version of Face algorithm

- 2D Face cannot be used directly in 3D



3D version of Face algorithm

- 2D Face cannot be used directly in 3D
- A 3D plane is created
  - Random plane
  - Source-dest-random point
  - ALSP



3D version of Face algorithm

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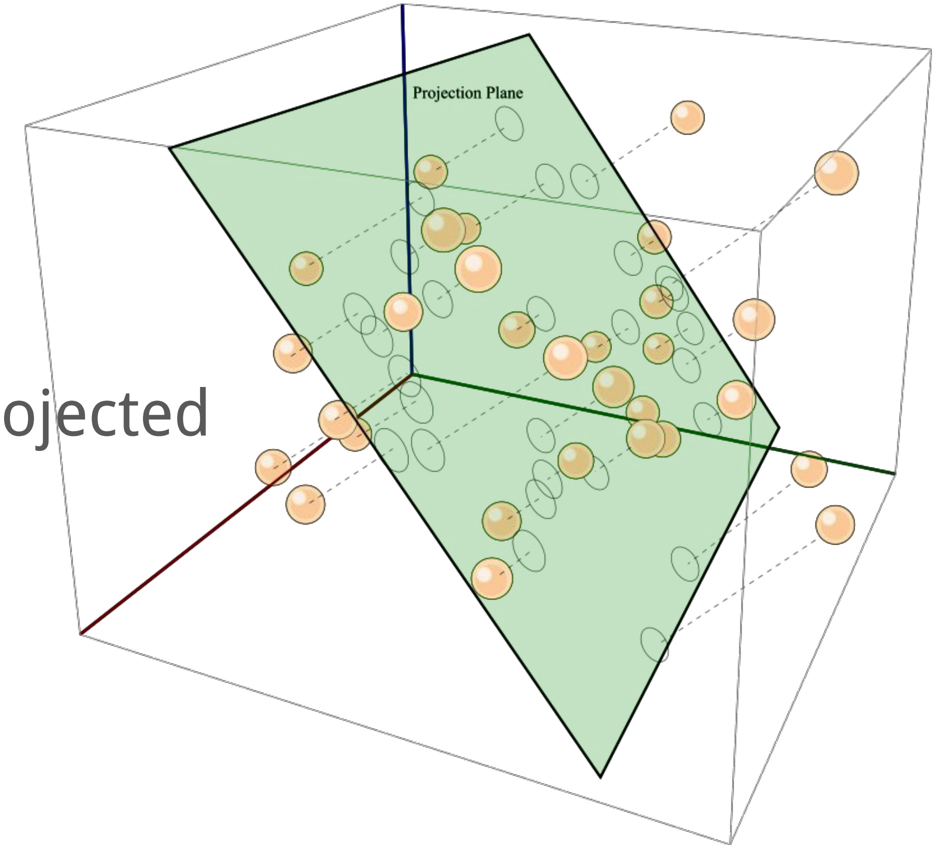
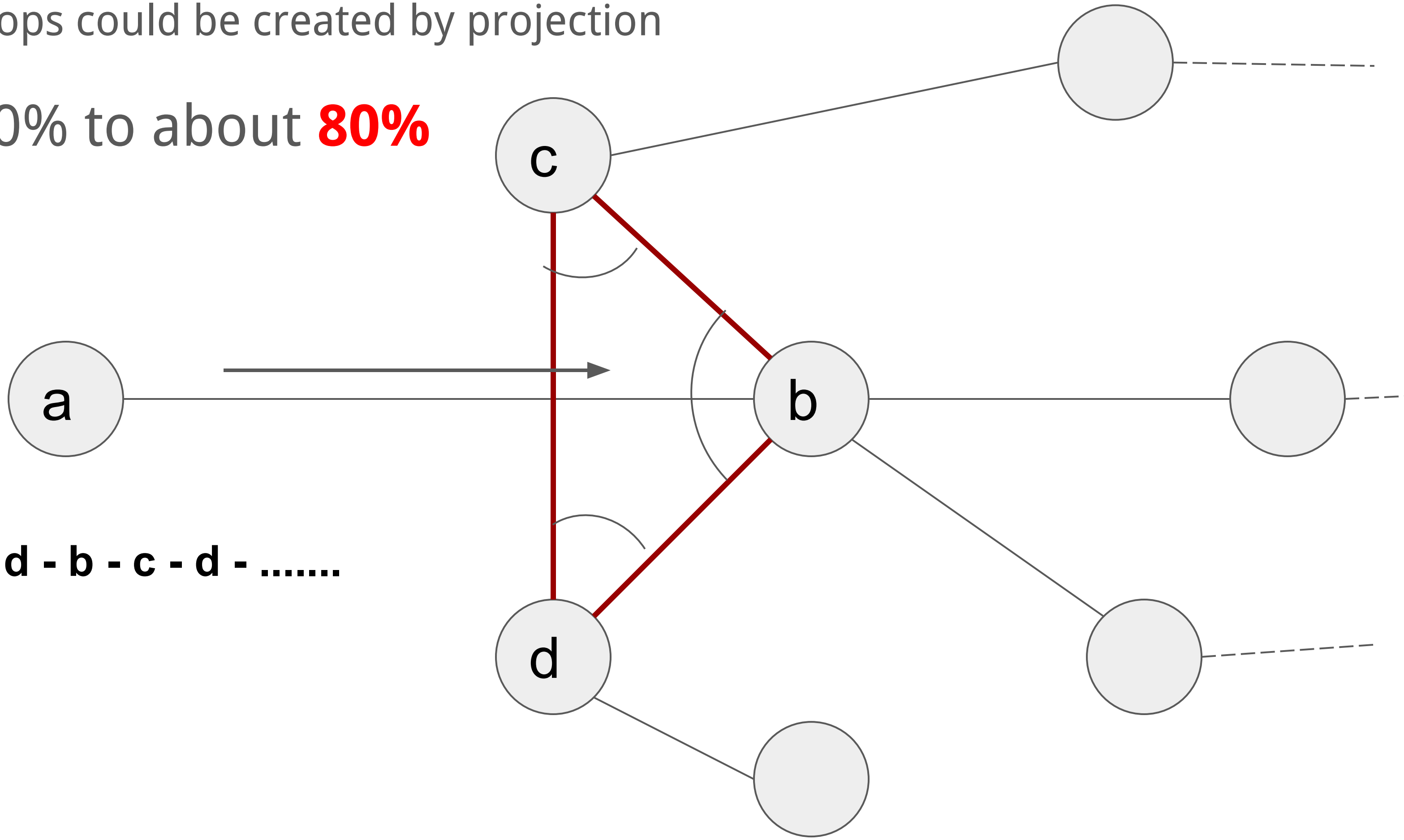
- 2D Face cannot be used directly in 3D
- A 3D plane is created
  - Random plane
  - Source-dest-random point
  - ALSP
- Project nodes on a plane
- Start face routing on this projected graph



3D version of Face algorithm

- Packet delivery is not guaranteed!!
  - Loops could be created by projection

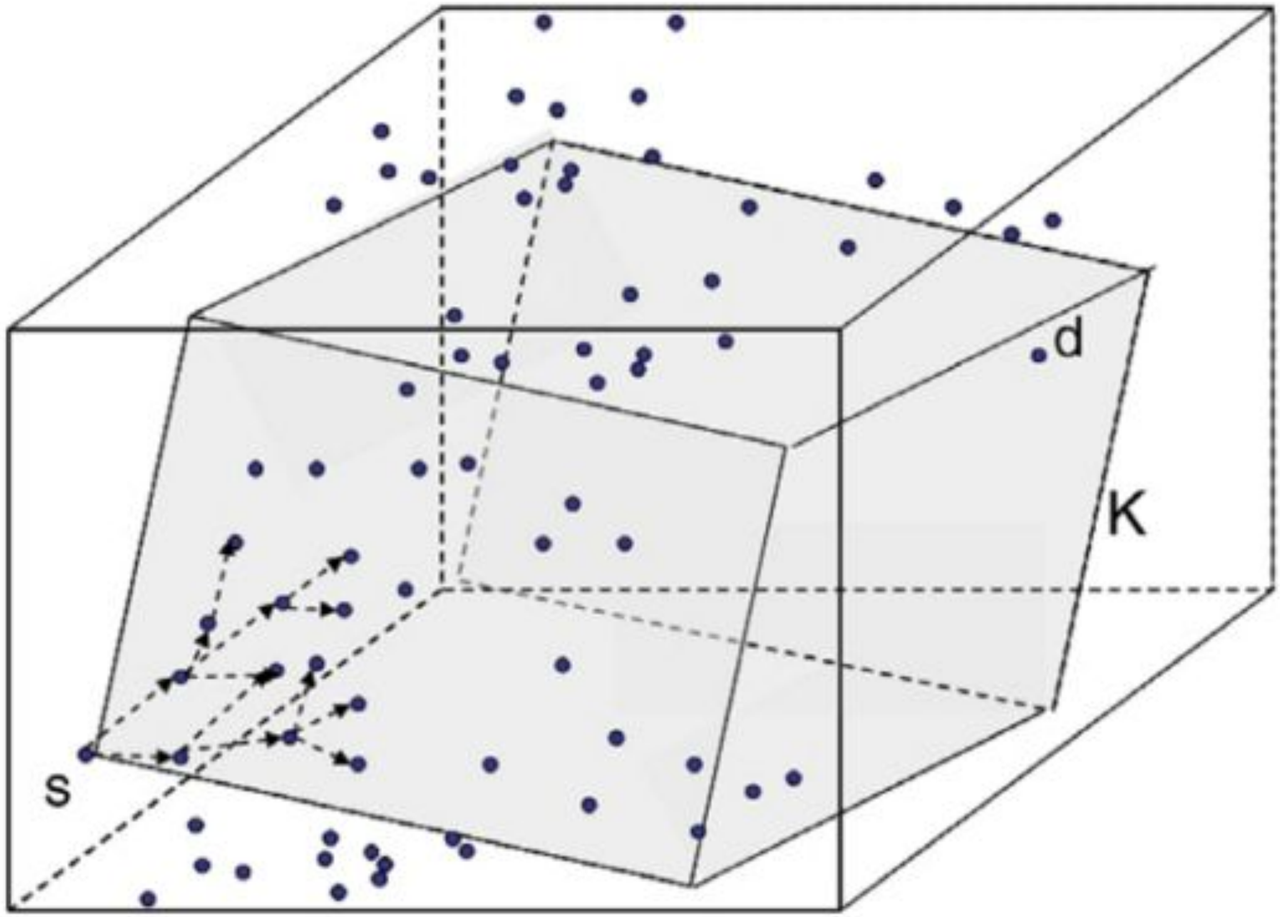
From 100% to about **80%**



a - b - c - d - b - c - d - ....

3D LAR

- 3D version of LAR



Performance simulation

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- NS-2 simulation environment
- Cube of 500 meters of side length
- Transmission range of 100 meters
- Network sizes: 50, 100, 150, 200 nodes
- Performance metrics
    - Delivery Rate
        - Percentage of delivered packets at the recipient
    - Path Dilation
        - Average ratio of the number of hops traveled to the minimum path length

Path Dilation:

$$\frac{\text{average hops traversed by the packet}}{\text{average hops of minimum path}}$$

Performance results (3D topology)

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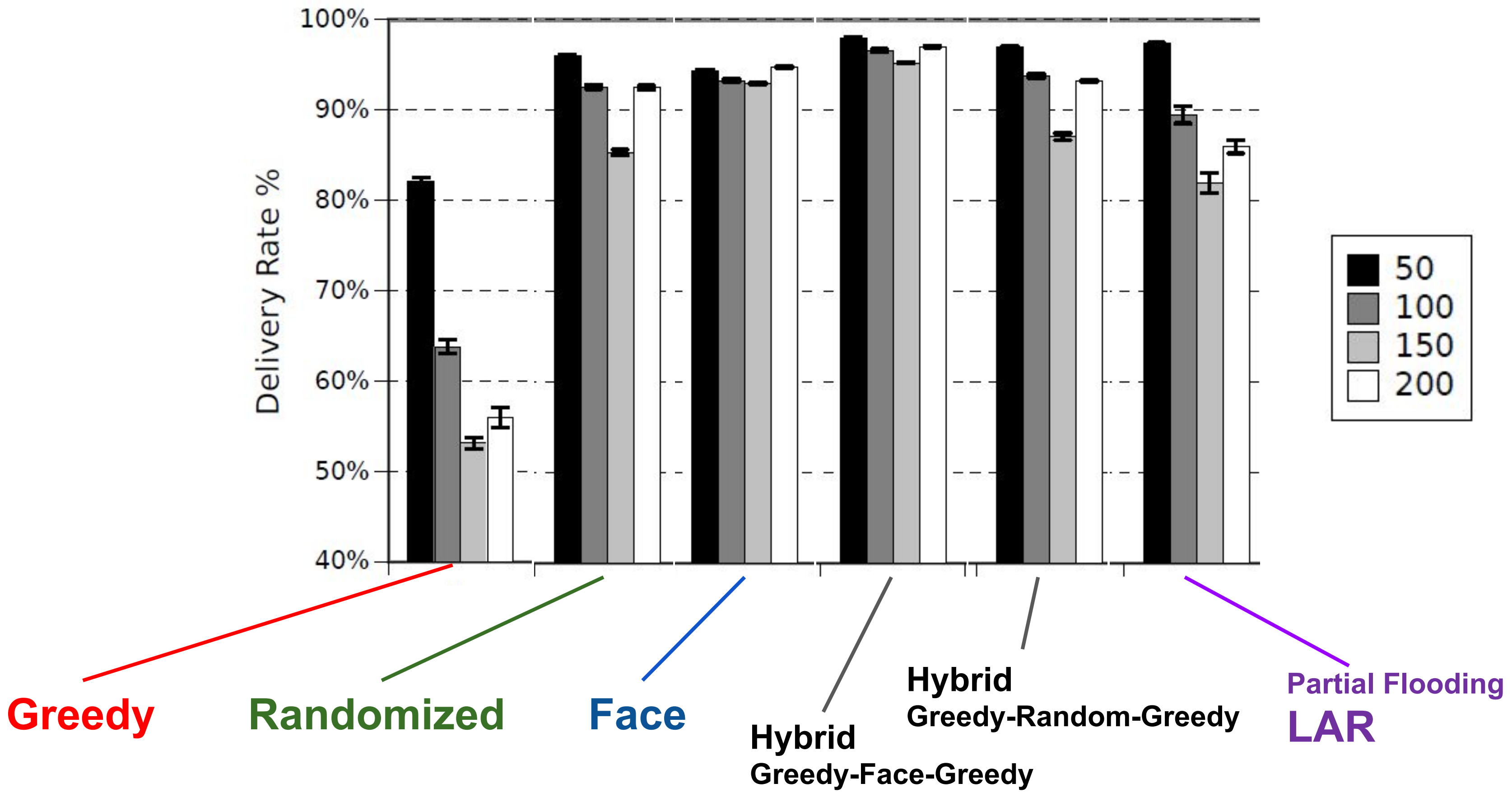
Packet Delivery Rate %

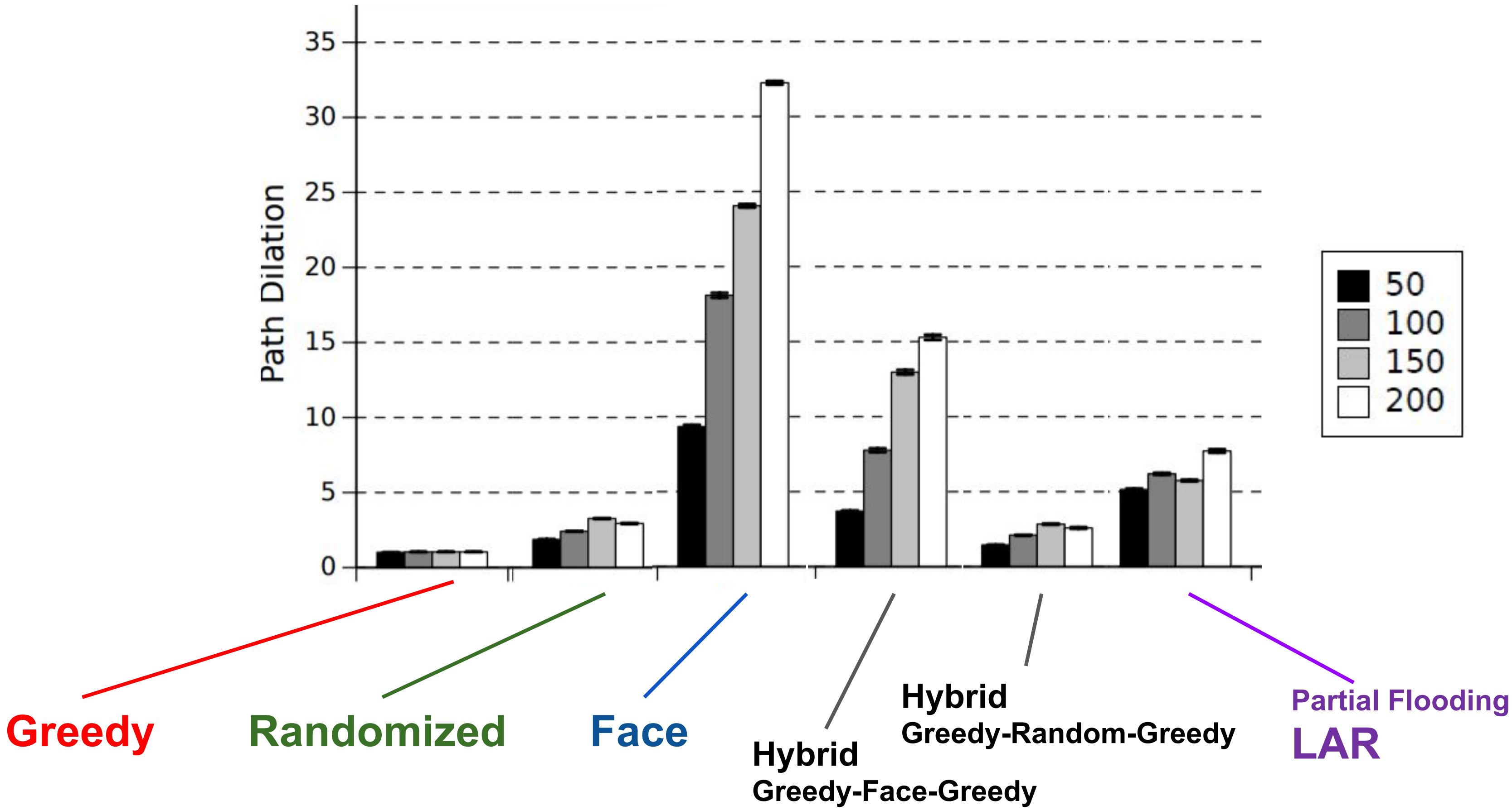
- Single Packet – 50, 100, 150, 200 nodes



Performance results (3D topology)

Path Dilation (#hops / # min path length)

- Single Packet – 50, 100, 150, 200 nodes



Performance results in IoV environment

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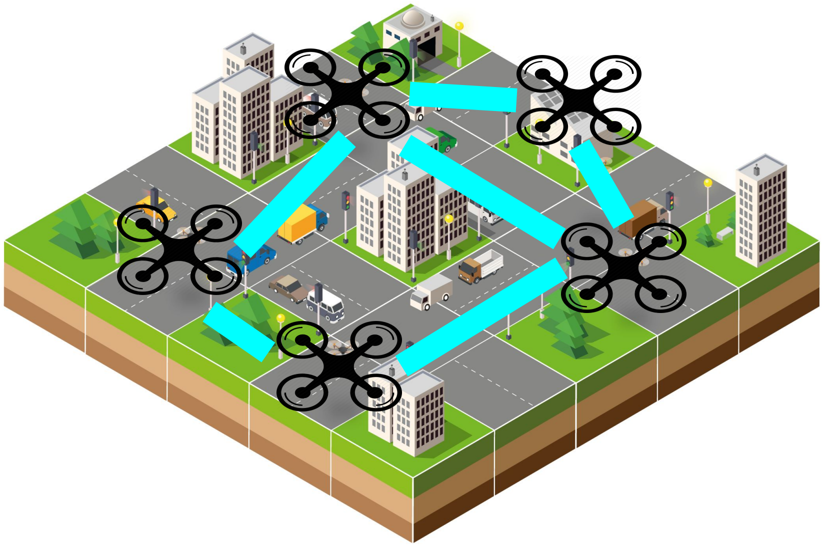
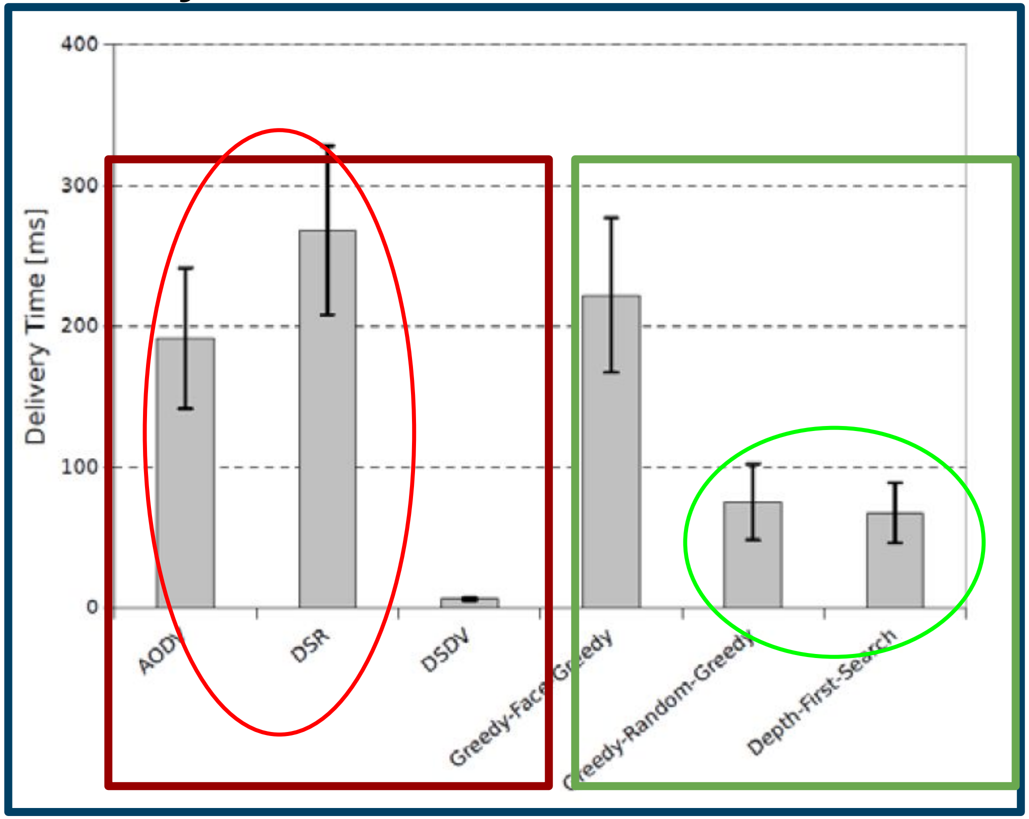
Topology vs **Position**

- NS-2 simulations
- Urban environment
- Vehicles and UAVs
- Realistic scenario



Delivery Time [ms]



- A. Bujari, C. E. Palazzi, D. Ronzani, "Would Current Ad-Hoc Routing Protocols be Adequate for the Internet of Vehicles? A Comparative Study", in IEEE Internet of Things Journal, 2018
- Bujari, M. Furini, F. Mandreoli, R. Martoglia, M. Montangero, D. Ronzani "Standards, Security and Business Models: Key Challenges for the IoT Scenario'', Mobile Networks and Applications, (first online) Feb. 2017. ISSN: 1383-469X (print). ISSN: 1572-8153 (online) (**IF: 3.259**).

Memory-based routing approaches

- **Stateless** routing protocols are based on **current** local information
  - Stateless characteristic makes them more scalable

HOWEVER

Make use of a little **memory** could help to hold more information and make routing protocols <u>more efficient</u>

- **Memory-based routing protocols**
  - Topology or past actions information is stored into
    - **Nodes**, or
    - **Packets**
  - Typical approach
    - Store the travelled nodes id into the packet's header
    - Avoid to return back

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Challenged Networks: Examples

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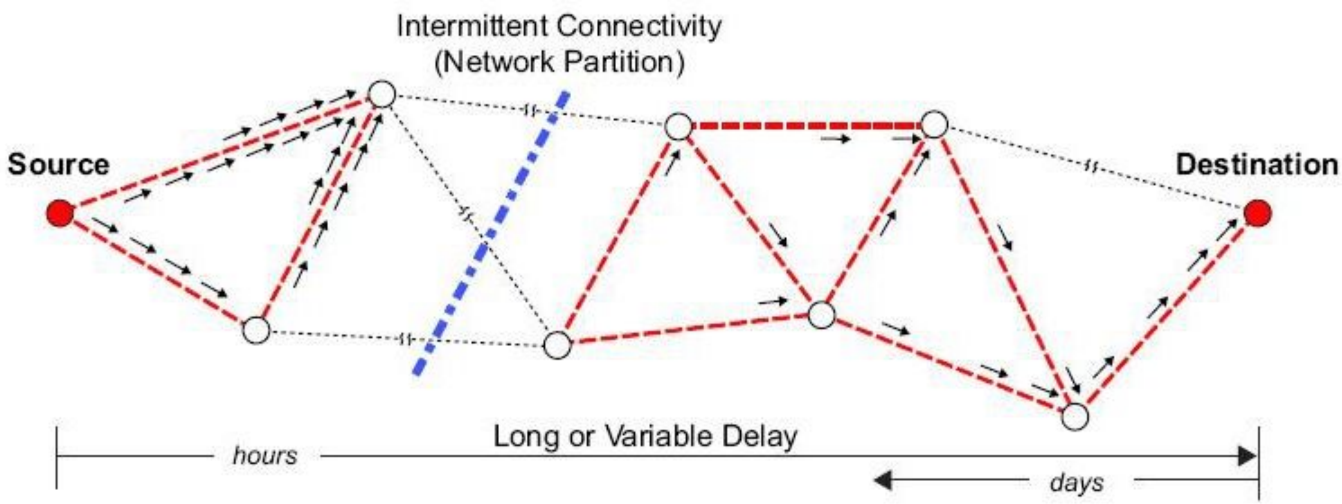
DTN - Delay Tolerant Networks

- Complexity at special nodes of the system
- Asynchronous (**store-and-forward)**
- On-demand, scheduled communication
- Typically **predictable links**

Delay Tolerant Networks

- FANET could be affected by intermittent connectivity
  - Several conditions could disrupt connectivity in a UAV network
- Shift to the ***Delay Tolerant Network*** paradigm

DELAY/DISRUPTION TOLERANT NETWORKING



Routing for DTNs

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- Routing in DTN works under different assumptions
  - Store and forward approach
  - Nodes act as carriers
- Typical DTN protocols:
  - **Epidemic** (flooding)
  - **Spray and Wait** (restricted flooding)
  - **MaxProp** (flooding with probability ordered packets)
  - **First Contact** (no copies, transmission to first met node)

- FANETs are often employed in mission oriented applications, following predetermined paths

  Can we exploit it?

Smart DTN aided routing for FANETs

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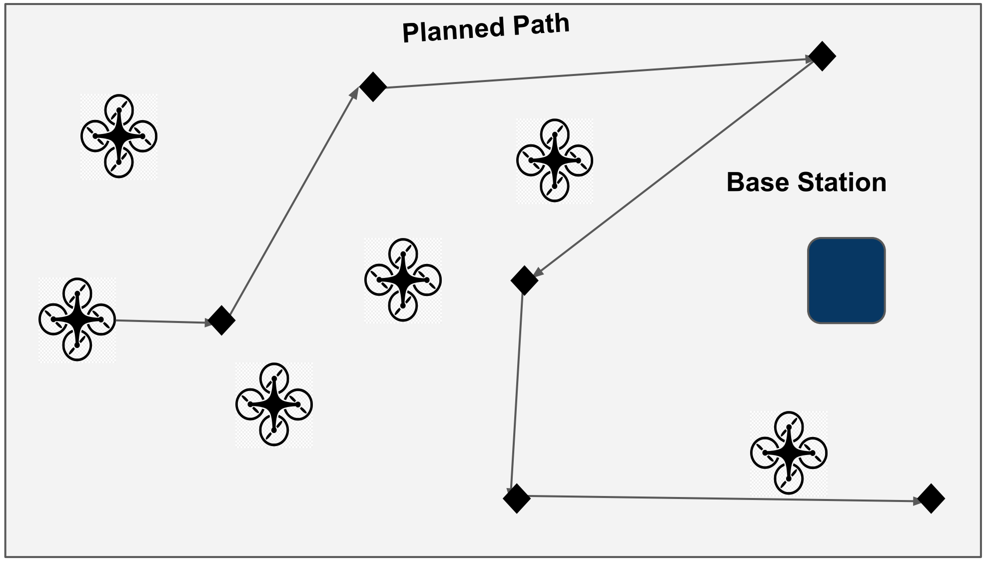
- *Use of **geographic and mobility waypoint information** to help the packet/bundle routing process in Smart DTN.*
- Context example: Search and Rescue operations

Each UAV analyzes the planned path of other UAVs to predict their locations.



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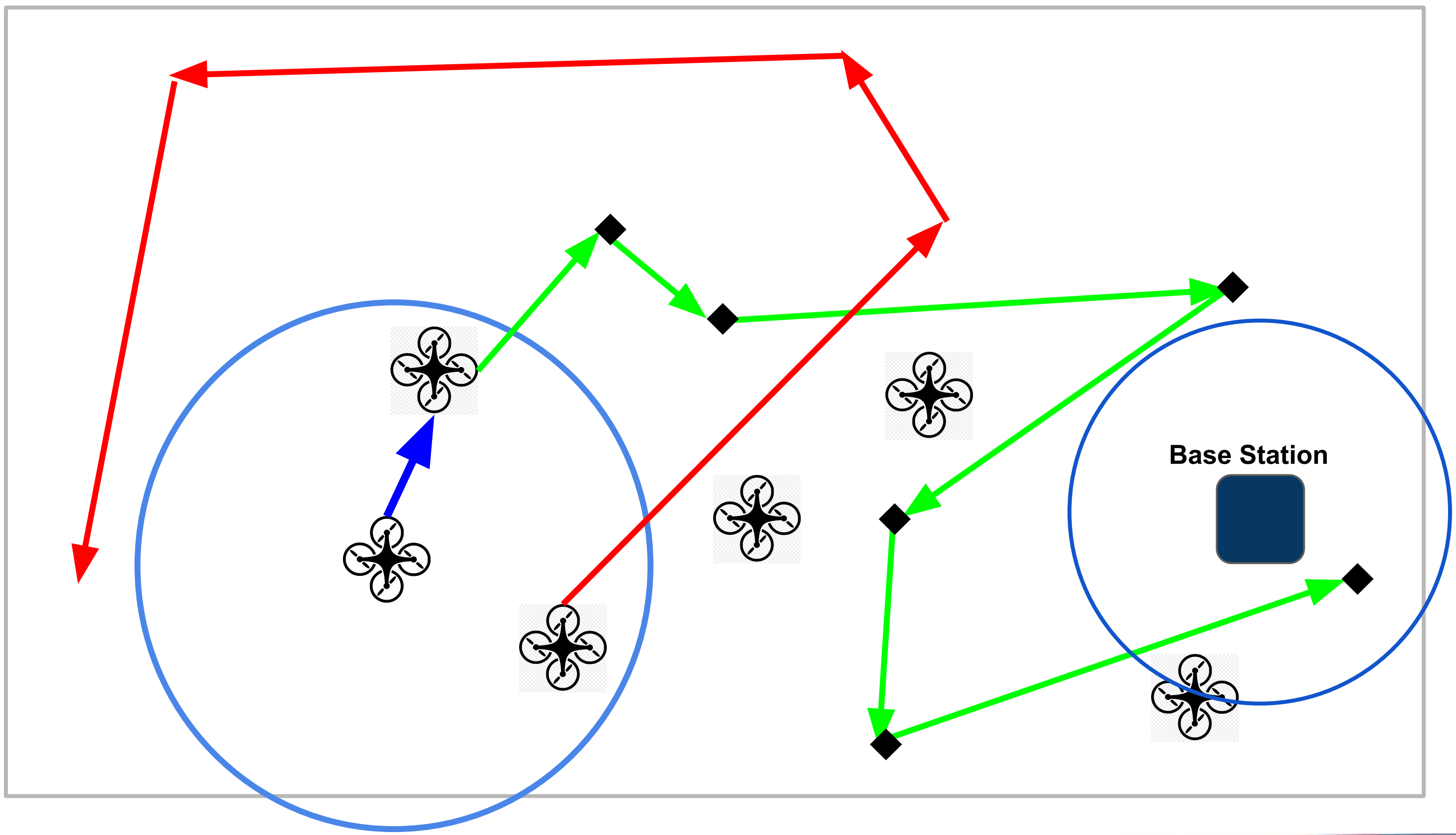
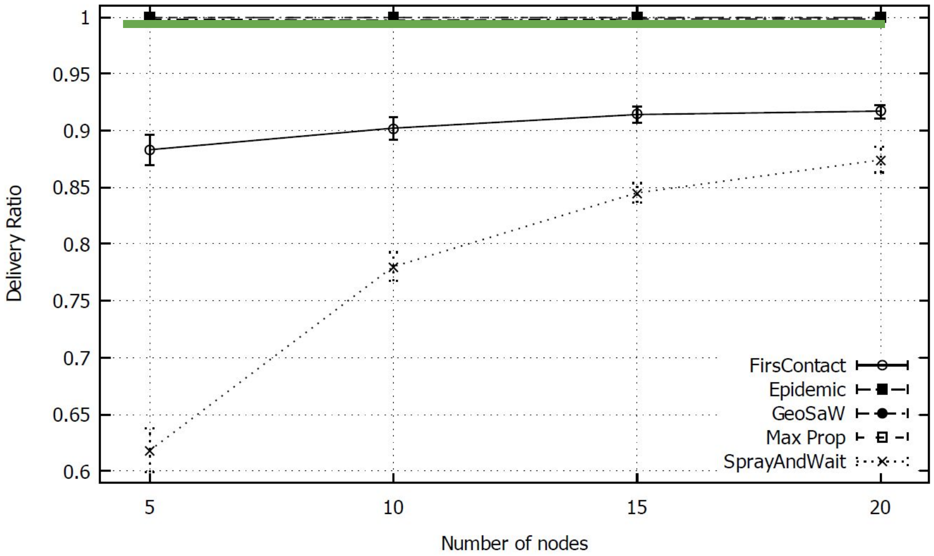
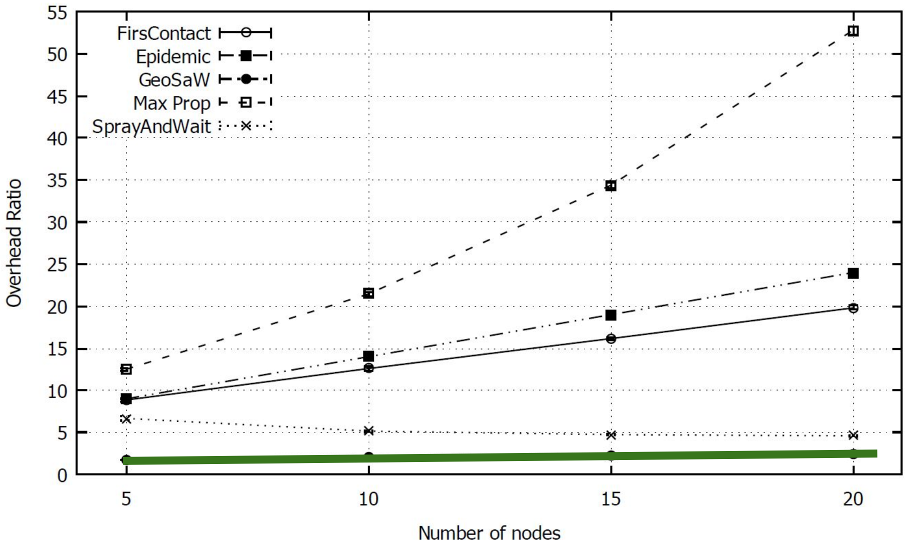
- The message is sent if a UAV is going to reach the vicinity of message's destination.



DTN FANET - Simulation Assessments





Good Results

Advantages in terms of ***delivery ratio*** and ***overhead*** with respect to the other DTN protocols.

Potential and realistic solution

- Many devices are nowadays equipped with a GPS
- Many applications require the vehicle path to be planned

Open Issue

- Still significant delay

Having more information about future events / objectives / actions could improve the routing approach

Armir Bujari, Carlos T. Calafate, Juan-Carlos Cano Pietro Manzoni, Claudio E. Palazzi, and Daniele Ronzani, Location-aware Waypoint-based Routing Protocol for Airborne DTNs, *Sensors, 2018.*

Some References

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